Presentation and validation of the spectral ageing model for Meteosat-7 Visible band

Ilse Decoster, N. Clerbaux, E. Baudrez, S. Dewitte, A. Ipe, S. Nevens, A. Velazquez Blazquez

Royal Meteorological Institute of Belgium (RMIB)
Satellite Application Facility on Climate Monitoring (CM SAF)
Vrije Universiteit Brussel (VUB)

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Outline

Background on current research
- Work within GERB framework
- Degradation process of MFG optics

Modelling of the ageing effects
- Preparation of time series
- Ageing model
- Results for Meteosat-7
- Validation of the model

Conclusions and future prospects

Work within GERB framework

- Part of the GERB team at the Royal Meteorological Institute of Belgium (RMIB), supported by Climate Monitoring SAF (CM SAF) of EUMETSAT
- Since 2004, the Meteosat Second Generation (MSG) satellites carry next to the narrow band imager SEVIRI also a broad band instrument called GERB
- In a geostationary orbit, GERB measures the Earth Radiation Budget through two broad band channels (VIS and TOT)
- Next to doing operational work, the GERB team at RMIB has experience in creating GERB-like data from SEVIRI through a NB-to-BB conversion

Work within GERB framework (2)

- Working on the generation of GERB-like data for Meteosat First Generation (MFG) satellites
- Only a narrow band imager onboard of the satellites: Meteosat Visible and Infrared Imager (MVIRI)

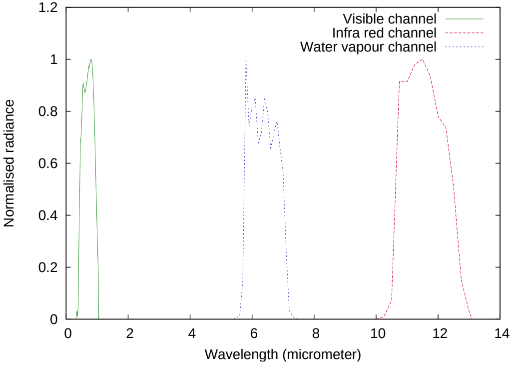

Figure: *Normalised spectral response curves for MVIRI channels.*

Work within GERB framework (3)

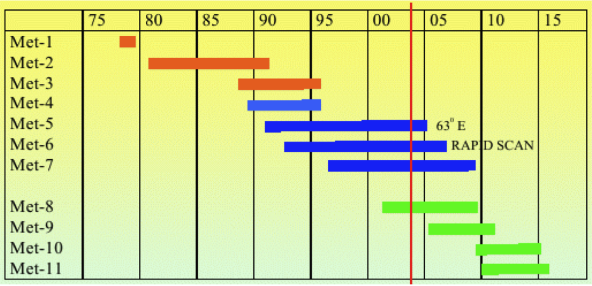

Figure: *Operational time for Meteosat satellites.*

- To create GERB-like data for MFG satellites, we will use overlap between MVIRI data from last MFG satellite without GERB instrument (Meteosat-7) and SEVIRI data from the first MSG satellite with GERB instrument (Meteosat-8).

Degradation process of MFG optics

Contamination of the mirror leads to a decrease in the reflectivity of the mirror.

⇒ the spectral response of the radiometer decreases in time and so the signal from the instrument will show a decreasing trend in time

⇒ contamination absorbs stronger in blue than in red, so that degradation is wavelength dependent

⇒ want to remove the trend by correcting the spectral response curve for ageing

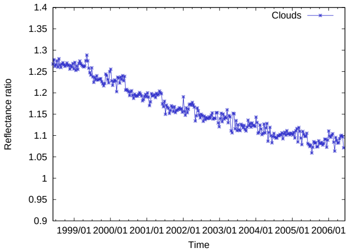

Figure: *Cloud time series for Meteosat-7.*

Degradation process of MFG optics (2)

For Meteosat-7 VIS Band, EUMETSAT uses a constantly increasing calibration coefficient of about 2.2% per year to correct for ageing (Govaerts et al. 2004):

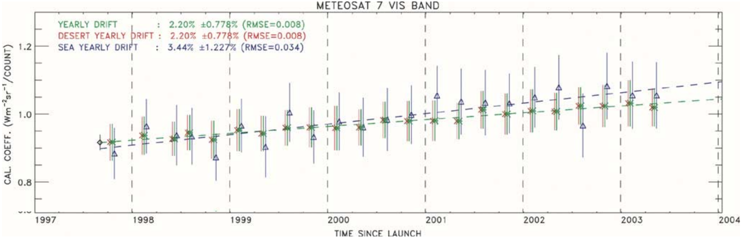

Figure: *Calibration coefficient Meteosat-7 (Govaerts et al. 2004).*

In this work the calibration coefficient was kept constant (value at launch) but a model was made to change the spectral response curve in time instead.

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Preparation of time series

Requirements:

- Both cloudy and clear sky time series
  - Clear sky images were created every 10 days through a pixel to pixel analysis of a series of 30 images before and 30 images after the original one
- Time series as constant as possible
  - Look for stable targets:
    - $\Rightarrow$ stable clear sky targets have lowest standard deviation in the total series of images
    - $\Rightarrow$ stable cloudy targets are chosen amongst the highly convective clouds, so the highest reflectance values
  - Averageing was done in space
- Clear sky time series for 5 different scene types
  - Scene types used: bright vegetation, dark vegetation, bright desert, dark desert and ocean

Preparation of time series (2)

Time series are expressed in reflectance ratio:

- Value of original images in counts
- **Radiance** obtained using a constant calibration:
  rad = calibration * (value - offset) $[W/(m^2\,sr)]$
- **Reflectance** obtained as:
  refl = rad / (irr * cos(SZA) * π * $(\text{dist})^2$)
- **Broad band reflectance** obtained by:
  $\text{refl}_{BB} = a + b\,\text{refl}$
  with a, b calculated through simulated NB-to-BB fits
- **Reflectance ratio** obtained by dividing the reflectance with a simulated reflectance to have flatter time series

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Preparation of time series (3)

- Obtain 6 time series: 1 for cloudy sky and 5 for clear sky with obvious decrease in reflectance ratio

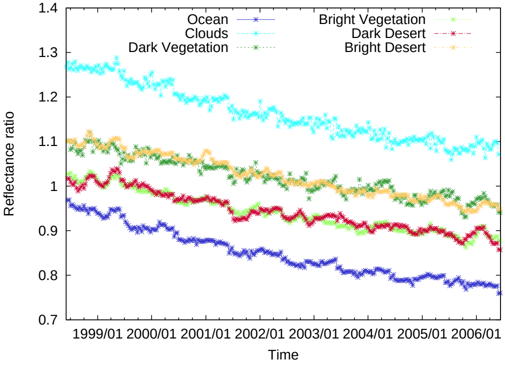


Figure: *Original time series for Meteosat-7.*

Ageing model

- Modelling decrease of spectral response curve $\phi(\lambda, t)$
- At time t_0, spectral response curve $\phi(\lambda, t_0) = \phi_0(\lambda)$

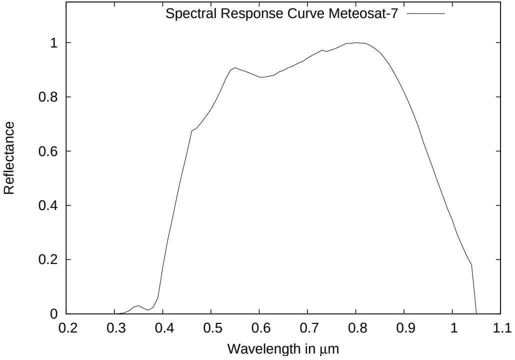


Figure: *Spectral Response curve for Meteosat-7 at launch.*

Ageing model (2)

Model the decrease of spectral response as a function of wavelength, time and some extra parameters:

$$\phi(\lambda, t) = f(\lambda, t, \alpha, \beta, ...)\, \phi_0(\lambda)$$

Create simulated narrow band (filtered) radiance $L_{NB,sim}$ from simulated reflectance values $L(\lambda)$ with spectral response function $\phi(\lambda, t)$:

$$L_{NB,sim} = \int_0^\infty L(\lambda)\, \phi(\lambda, t)\, d\lambda$$

Create simulated broad band (unfiltered) radiance $L_{BB,sim}$ from simulated reflectance values $L(\lambda)$ with a constant spectral response curve $\phi(\lambda, t) = 1$:

$$L_{BB,sim} = \int_0^\infty L(\lambda)\, d\lambda$$

Ageing model (3)

Establish linear relation between $L_{NB,sim}$ and $L_{BB,sim}$:

$$L_{BB,sim} = a + b\, L_{NB,sim}$$

Convert narrow band (filtered) observations $L_{NB,obs}$ to broad band (unfiltered) observations $L_{BB,obs}$ through this relation:

$$L_{BB,obs} = a + b\, L_{NB,obs}$$

$\Rightarrow$ Results in broad band (unfiltered) time series that are corrected for the degradation process.

Results for Meteosat-7

Final model with best set of parameters $(\alpha, \beta, \ldots)$ must lead to 6 straight broad band reflectance ratio time series.

Best model that was found:

$$\phi(\lambda, t) = \phi_0(\lambda)\left[e^{-\alpha\, t} + \beta\left(1 - e^{-\alpha\, t}\right)\right]\left(1 + \gamma\, t\,(\lambda - \lambda_0)\right)$$

with parameters (α, β, γ) and $\phi_0(\lambda)$ the spectral response curve of Meteosat-7 at launch.

Simulated radiance values $L(\lambda)$ used:

$\Rightarrow$ for clear sky: using CERES data

$\Rightarrow$ for the convective clouds: using LibRadtran

Results for Meteosat-7 (2)

Translating simulated reflectances to filtered reflectance:

$$L_{NB,sim} = \int_0^\infty L(\lambda)\,\phi(\lambda,t)\,d\lambda$$

$$\begin{aligned} L_{NB,sim} &= \int_0^\infty L(\lambda)\,\phi(\lambda,t)\,d\lambda \\ &= \int_0^\infty L(\lambda)\,\phi_0(\lambda)\,[e^{-\alpha\,t} + \beta\,(1 - e^{-\alpha\,t})]\,. \\ &\qquad (1 + \gamma\,t\,(\lambda - \lambda_0))\,d\lambda \end{aligned}$$

$$L_{BB,sim} = \int_0^\infty L(\lambda)\,d\lambda$$

Linear relationship between $L_{NB,sim}$ and $L_{BB,sim}$ was calculated for a range of angles and scene types and was applied to the Meteosat-7 observations $L_{NB,obs}$.

Results for Meteosat-7 (3)

Best found parameters are:

$$
\begin{aligned}
\text{alpha:}\quad & 0.000300 \text{ days}^{-1} \\
\text{beta:}\quad & 0.750000 \\
\text{gamma:}\quad & 0.000120 \text{ days}^{-1}\,\mu m^{-1}
\end{aligned}
$$

Resulting time series:

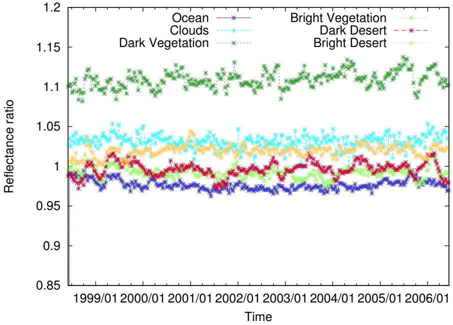
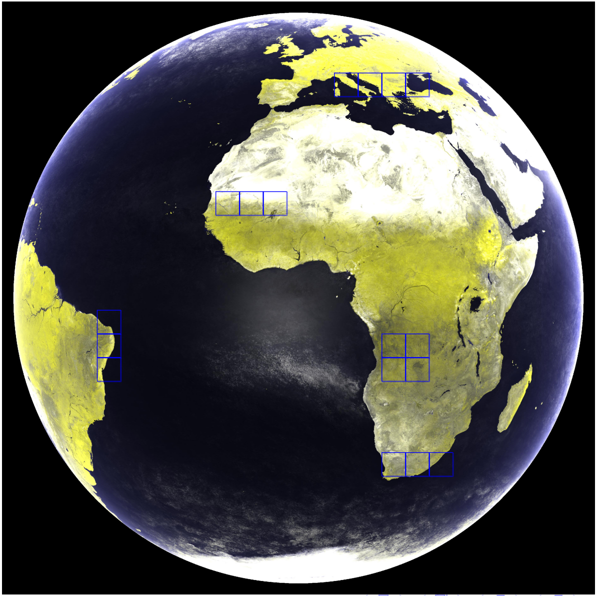


Figure: *Corrected time series for Meteosat-7.*

Validation of the model

- One validation that has been done so far was to use the cloudy simulations made from CERES data on the original images instead of the clear sky simulations on clear sky images.
- The narrow band to broad band correction was then done using CERES data with clouds.
- Certain boxes in the Meteosat field of view were chosen where different scene types were present.
- For each pixel the degradation correction was applied.

Validation of the model (2)



Ageing model of Met-7 VIS band
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Validation of the model (3)

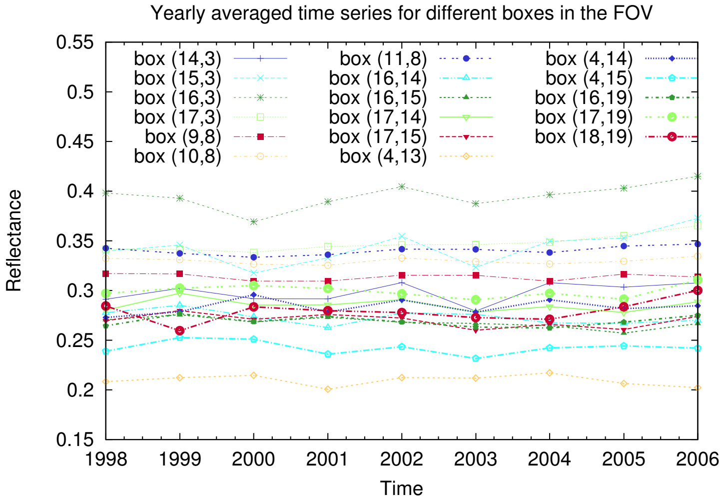

Figure: Yearly averaged validation time series for different boxes in the field of view.

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- Aim to create GERB-like data for Meteosat First Generation Satellites
- First ageing problem needed to be handled: model was created and validated for Meteosat-7
- Future:
  - Further validation of model using both original images and clear sky images
  - Apply the model on Meteosat-2 until Meteosat-7
  - Publication on model is in preparation